Forewarnings of Coming Hazards

Modeling atmospheric emergencies is the business of Livermore's Atmospheric Release Advisory Capability. As ARAC stands on call to assist with present-day atmospheric threats, it anticipates and prepares for future ones.

An emergency response team at Lawrence Livermore's Atmospheric Release Advisory Capability's Emergency Operations Center mobilizes to model an atmospheric release. Pictured (clockwise from top right) are: Ron Baskett, Fernando Aluzzi, Connee Foster, Jim Ellis, John Pace, Brent Bowen, Phil Vogt, Mike Bradley, and Brenda Pobanz.

THE call for help came from halfway around the world. In the Philippines, Mount Pinatubo was erupting cataclysmically, spewing volumes of ash into the atmosphere. Strong, high-altitude winds were transporting the clouds of ash over the South China Sea into Southeast Asia, India, and beyond. Continuing eruptions darkened the sky over the Philippines, blanketing the area with ash and bringing most activity to a standstill. Worse yet, monsoon storms converted some of that ash into a flood of mud that descended on numerous villages. Evacuating U.S. military personnel and dependents at Clark Air Base and Subic Naval Base became imperative. But first, the volcanic ash plumes had to be tracked, so that safe flight paths could be planned for the military aircraft transporting evacuees home to the United States.

The U.S. Air Force turned to Lawrence Livermore's Atmospheric Release Advisory Capability (ARAC), which was founded in the late 1970s to predict the dispersion of radioactivity into the atmosphere during nuclear accidents, threats, attacks, and terrorist incidents. The Air Force was presenting a problem of quite a different sort, one that fit well within ARAC's capabilities. ARAC scientists expanded three-dimensional atmospheric models up into the jet stream and beyond-to an altitude of over 100,000 feet (Figure 1). For five days, they simulated the complex and divergent ash clouds and predicted its movement two days into the future, thus helping pilots dodge ash clouds that could damage aircraft engines and instrumentation.

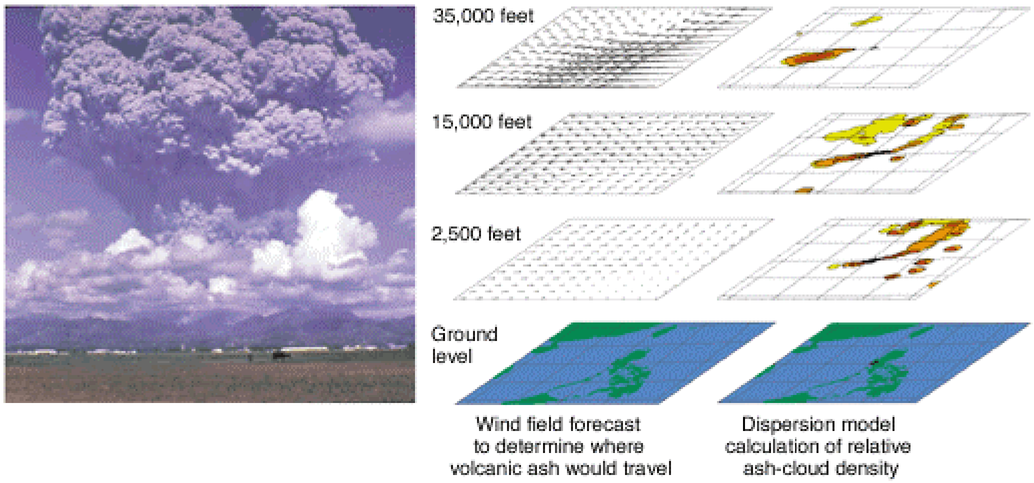


Figure 1. When Mount Pinatubo in the Philippines erupted in June 1991, the complex three-dimensional atmospheric structure of the region produced dramatically divergent ash-cloud patterns. Meteorologists from Livermore's Atmospheric Release Advisory Capability Center developed extensive daily analyses and forecasts of the ash-cloud positions two days into the future.

Providing Emergency Readiness

ARAC is one of many emergency response organizations sponsored by the U.S. government to counter dangers and threats to the nation. Over the years, its charter to simulate radionuclide dispersion from nuclear incidents has expanded to include working with all manner of toxic and hazardous releases. ARAC today can predict the transport and fate of material released during disasters, whether natural or caused by human activity. ARAC makes predictions not only during atmospheric releases but also for contingency planning purposes, before a potential one might occur. ARAC conducts detailed postevent analyses as well.

The organization has evolved considerably since the first atmospheric dispersion estimates were made in the 1960s. Then, scientists at Lawrence Livermore were engaged in the Plowshare Program, an effort to use nuclear technology for civilian and commercial purposes. Projects such as excavating harbors and canals with nuclear explosives required estimates of the path of radioactive particles that could be lofted into the atmosphere.

The first rudimentary Plowshare calculations determined only the speed and direction of radioactive dispersion. But they were enough to cement the idea that tracking radionuclides was a useful and necessary task. In ensuing nuclear-related projects, the Laboratory's atmospheric scientists continued to improve methods and approaches for nuclear dispersion calculations and used the tools as part of efforts to contain radioactivity from underground nuclear tests. The calculations demonstrated a nascent, useful capability and led to funding for an operational system in the late 1970s and ultimately for the organization that is today's ARAC. Fortuitously, ARAC was scheduled to be up and running two days after the accident at Three Mile Island.

The Department of Energy provided ARAC with its first funding. Later, in the mid 1980s, the Department of Defense also became a major funder, enabling a major expansion and automation of the system. Both DOE and DoD wanted the system to be networked so that it could provide aid during atmospheric release emergencies to an increasing number of their facilities around the U.S. By 1988, ARAC served over 70 government sites.

Improving with Experience

For two decades, ARAC has benefited from experience gained during more than 160 alerts and incident responses. For example, in providing assistance during the 1986 Chernobyl accident in the former Soviet Union, ARAC had to enlarge its models to handle continental-to-hemispheric scales. Subsequently, the group expanded its meteorological, terrain, and mapping data to cover Earth. The large volume of data prompted improvements to ARAC's computer systems and software to increase throughput and reduce response time.

ARAC also advances its capabilities through continuous training exercises, simulating emergency atmospheric release scenarios several times a week in cooperation with supported sites and agencies. In an exercise performed in March 1999, the organization supported the U.S. Navy in its Fleet Battle Experiment-Echo to test new technologies and tactics for combating terrorist attacks. ARAC scientists modeled chemical attack scenarios in Oakland and San Francisco and delivered simulation results in minutes to the command ship, the USS Coronado. They collaborated with Livermore's Nonproliferation, Arms Control, and International Security scientists, who created a Web browser interface to allow Navy personnel on board the Coronado to tap into the ARAC system easily. With information provided by the Coronado, ARAC simulated two attacks: a truck explosion that released chlorine at the San Francisco-Oakland Bay Bridge toll plaza and a release of sarin (a nerve gas) north of Pier 35 from an airplane flying across San Francisco Bay. The results (Figure 2) allowed the Coronado's medical staff to understand the progression and concentration of the chemical plumes and therefore advise where to best deploy emergency services.

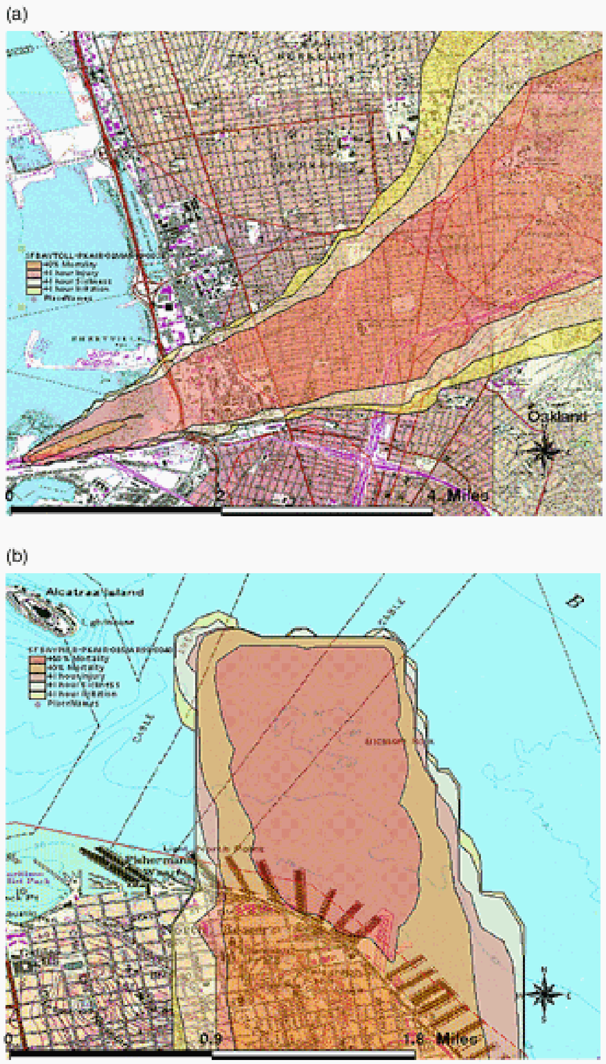


Figure 2. During a recent U.S. Navy emergency response training exercise, ARAC scientists were called on to simulate (a) a chlorine release following a truck explosion at the San Francisco–Oakland Bay Bridge toll plaza and (b) a release of sarin north of Pier 35 in San Francisco from an airplane flying over San Francisco Bay. Simulations such as these tell emergency response personnel where to best deploy emergency medical services.

Dealing with Complexities

Simulations of the atmospheric dispersion of hazardous gases, aerosols, or particulates start with information about the release: its location and time and the initial size of the cloud or mechanism of the release. To this data, atmospheric modelers must add information about the processes that play a role in dispersing, transforming, and depositing the material. Different meteorological factors are important in modeling a release, depending on its magnitude and type.

Initially, the wind speed and direction at the release location control the plume's path. Accurately determining the winds at the accident site is paramount to producing a credible result. If the release involves a powerful explosion or fire, the winds thousands of feet above the ground may determine the plume's transport, and its vertical extent may be limited by a temperature inversion in the atmosphere. As the plume travels downwind, turbulence dilutes the plume by mixing the material vertically and horizontally, which the modeler must estimate. In addition, local wind systems (such as sea breezes) or terrain may change the plume's path. Mountain ridges can block flows, and valleys are channels for winds. Furthermore, material may be removed from the plume by being deposited on the ground or washed out by precipitation.

The ARAC Emergency Response Modeling System (Figure 3) accounts for these effects through the use of a series of codes that represent the third-generation modeling system in ARAC's 20-year history. The first code, GRIDGEN, draws on a terrain database with a 500-meter resolution covering most of the globe to develop the underlying terrain and numerical grid for the area where the dispersion occurred. The second code, ADAPT, creates three-dimensional wind fields using worldwide meteorological data obtained from on-line links to the Air Force Weather Agency or weather forecasts from the U.S. Navy and the National Oceanic and Atmospheric Administration.

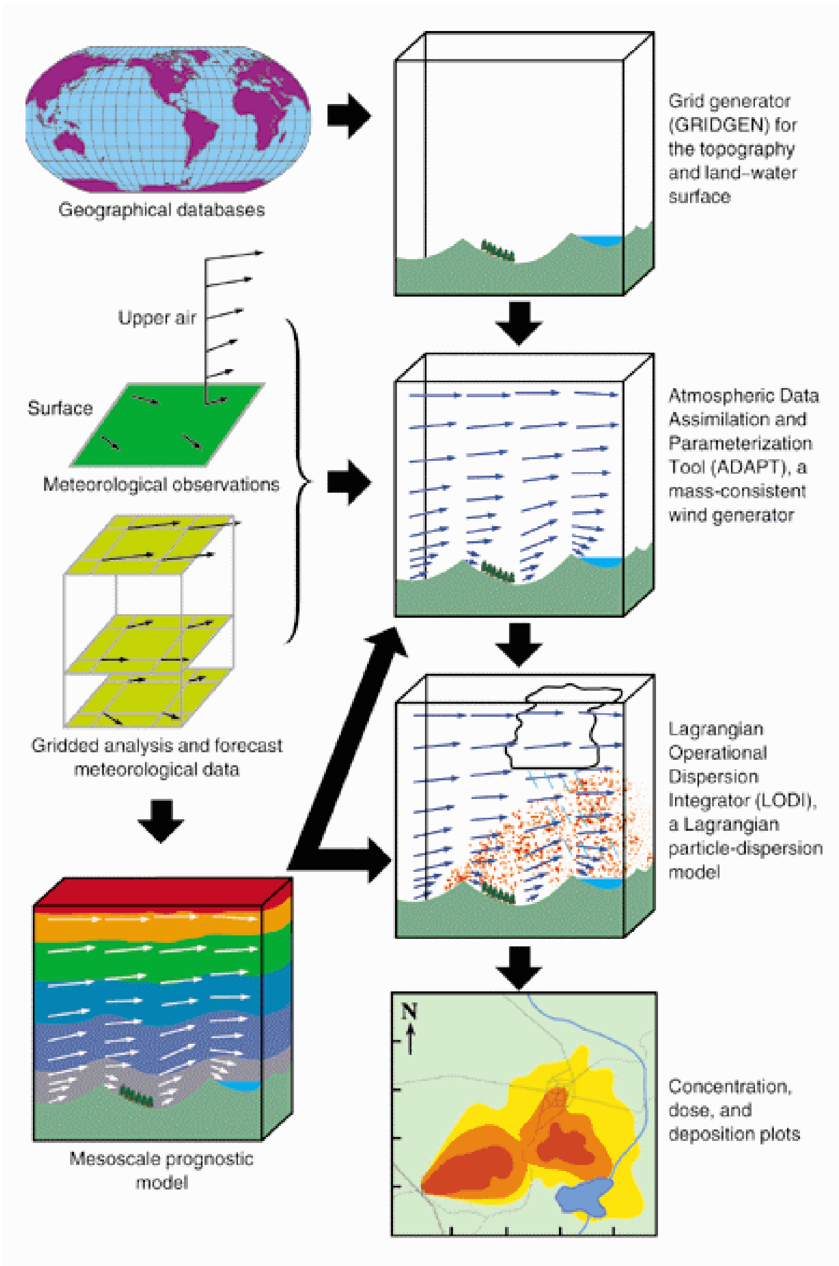


Figure 3. The series of codes in the ARAC Emergency Response Modeling System accounts for physical processes that affect the dispersion of hazardous material in the atmosphere. Taking terrain information from a database, GRIDGEN develops the topographical grid for the area of interest. ADAPT uses observed and forecasted weather data to develop three-dimensional wind fields and adjusts them to account for the influence of topography. LODI simulates the release, transport, diffusion, and deposition of particles.

If the event needs to be projected several days into the future, ARAC may run its own version of the Navy's Coupled Ocean-Atmosphere Mesoscale Prediction System model to generate detailed wind data. Based on terrain and weather descriptions, ADAPT approximates the local wind velocities (interpolating more detail when actual measurements are sparse) and then adjusts the winds to account for the influence of the topography. For example, it might show how hills deflect the oncoming wind flow and how wind is channeled through passes.

LODI, the third code, simulates the release, transport, diffusion, and deposition of a release by using numerical marker particles, that is, the positions in space representative of the released material. Finally, a graphics code converts the data to plots of interest, such as doses for radiological accidents, air concentrations for chemical releases, or ground deposition. The plots are displayed on a map of the model domain.

The ARAC system can model problems of any scale anywhere in the world. Versatile and accurate, its models are ranked in the top tier of atmospheric dispersion models in use throughout the world. But the models must be supplemented by scientific expertise and experience. The variety, complexity, and data limitations of atmospheric dispersion problems challenge all modeling systems. Thus, it takes an experienced atmospheric scientist to guide the models toward the best solutions.

Prepared for Contingencies

In October 1997, the National Aeronautics and Space Administration launched the Cassini spacecraft to study Saturn. Cassini was notable not only for its scientific mission but also for the radioactive material-specifically, plutonium-238-it carried to supply heat and electrical power. Cassini's generators and heat units had been designed to withstand almost any catastrophic event, and NASA pronounced its chances of releasing nuclear material in an accident as close to nil. Nevertheless, federal regulations required DOE to be prepared for emergency response during Cassini's launch in the unlikely event that Titan IV-the carrier rocket-exploded.

DOE selected ARAC for contingency planning and response. Before the launch could start countdown, ARAC predicted where hazardous material might be dispersed during an accident, so NASA could make the necessary preparations for that possibility.

Both real-time and forecasted weather information were crucial to the modeling effort. The complex wind patterns that occur around Cape Canaveral are particularly challenging to simulate. With assistance from the Air Force, ARAC staff deployed in Florida obtained the necessary real-time meteorological data from over 40 locations and communicated it to Livermore using dedicated circuits via a field satellite unit provided by DOE's Remote Sensing Laboratory from Las Vegas.

ARAC scientists used NASA and DOE safety studies on rocket explosions to develop the initial conditions for a radioactive release from a potential Titan accident. The studies predicted the configuration of the explosion or fire cloud and the status of the radioactive material (Figure 4).

At regular intervals during the launch countdown, ARAC provided NASA with information on the potential radioactive dose to affected populations and the amount of radioactive materials that would be deposited on the ground. These plots would have been used to plan ground-level and airborne plume sampling, had that become necessary.

Fortunately, Cassini's launch was perfect, and the preparations for emergency response support were never needed. Nevertheless, they demonstrated a timely and effective analysis capability for predicting the position and course of a hazardous plume, should an accident ever occur.

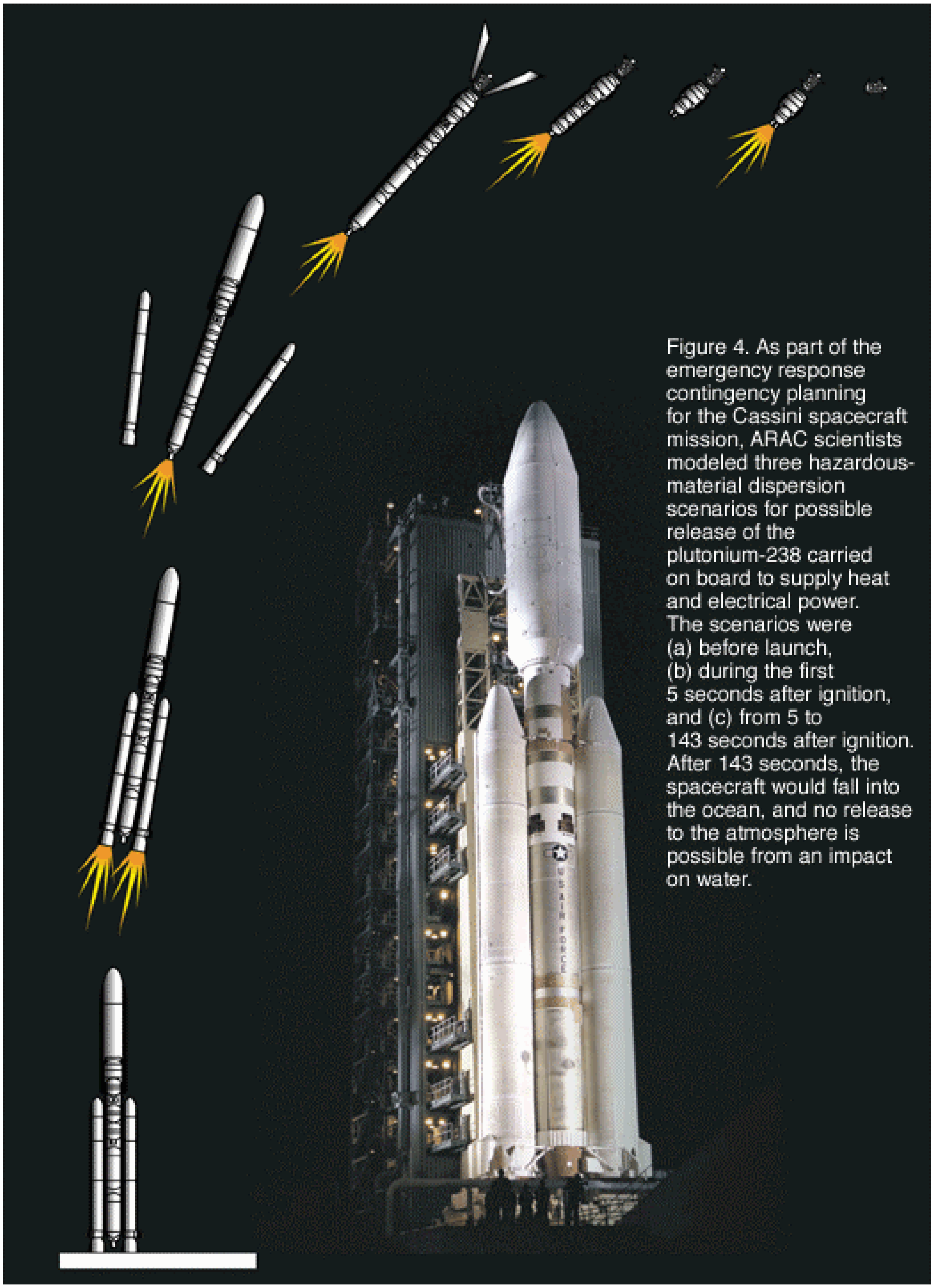


Figure 4. As part of the emergency response contingency planning for the Cassini spacecraft mission, ARAC scientists modeled three hazardous-material dispersion scenarios for possible release of the plutonium-238 carried on board to supply heat and electrical power. The scenarios were (a) before launch, (b) during the first 5 seconds after ignition, and (c) from 5 to 143 seconds after ignition. After 143 seconds, the spacecraft would fall into the ocean, and no release to the atmosphere is possible from an impact on water.

Closing in on the Source

In the extreme southern tip of Spain, near the town of Algeciras, an accidental release of cesium provided an opportunity for ARAC to use actual, if sparse, measurements of a dispersion to back-calculate the magnitude and extent of the original release.

On June 9, 1998, the Swiss government announced that radiation levels up to a thousand times background had been detected by their national monitoring network. The source was unknown. France and Italy also reported measurements.

The next day, a steel mill near Algeciras notified the Spanish Nuclear Security Agency that radiation had been detected in one of its oven filtration systems. The agency, however, had not observed elevated radiation levels in its network. On June 12, the source of the release was identified as a medical radiotherapy device containing cesium-137 that apparently melted in the steel mill's scrap metal furnace. The amount and time of the release were unknown, but the incident was thought to have taken place during the last week of May 1998.

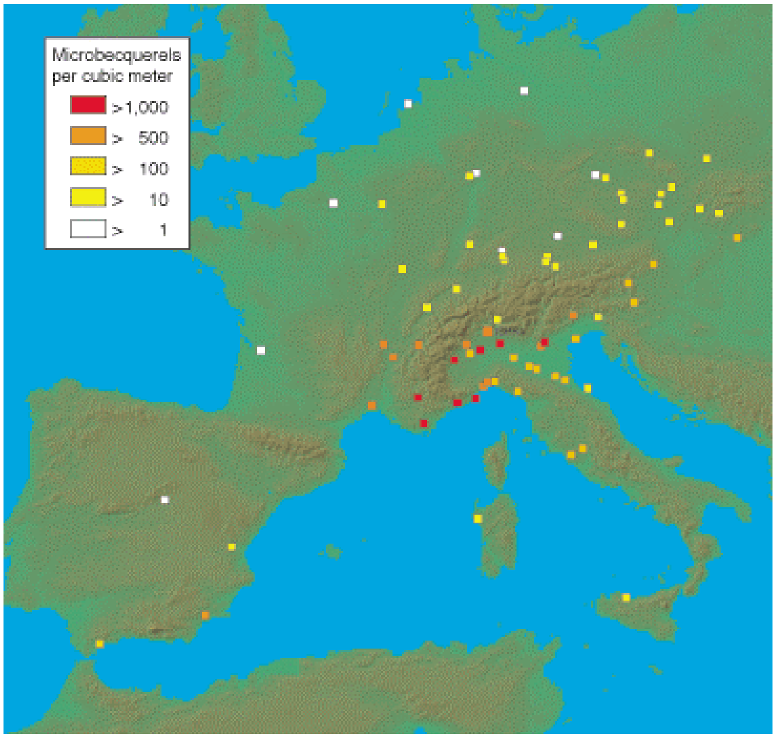
On June 12, the International Atomic Energy Agency also announced the incident and speculated on its possible connection to elevated levels of cesium-137 detected at the end of May and early June in southern Europe.

As ARAC staff became aware of the incident, they assessed gridded meteorological data archived for the area and began acquiring preliminary ambient cesium air concentration measurements from European colleagues. The various countries offering data had collected them with different samplers, using different averaging times (ranging from 1 to 14 days) and different radiological sensitivity thresholds. Having only data of sparse and varying quality, the staff set themselves the challenge of modeling the incident without knowing the exact location of the release. With each successive simulation, they incorporated new data as they were received and made model adjustments based on what they learned from previous simulations.

The first simulation led to an estimate of a 100-curie (370-gigabecquerel) release of cesium-137 over a 12-hour period on May 29, 1998. At that point, ARAC received more data on concentrations of cesium in the air at greater distances downwind, that is, from eastern and central Europe. ARAC enlarged the model domain to include these data. It also decreased the release duration from 12 hours to 30 minutes, based on results from the first model run. By the third simulation, the exact location of the steel plant releasing the cesium became known and was incorporated into the model, as were the parameters of the stack responsible for the release. Once this location was pinpointed, ARAC meteorologists blended observed meteorological data from the area with gridded weather data and produced their final simulation. It led to an estimate of a 50-curie (1,850-gigabecquerel) release, which compared favorably with the 8- to 80-curie (296- to 2,960-gigabecquerel) estimate provided by the Spanish government (Figure 5).

The Algeciras release was too small to produce any measurable health effects. However, the fact that ARAC tracked even this small release for great distances demonstrates the potential of accidental releases to affect substantial geographic areas and populations. ARAC used the Algeciras release to refine and validate techniques and to test its ability to model on large spatial scales. The postaccident analysis proved to be an excellent demonstration of ARAC's capability.

(a)



(b)

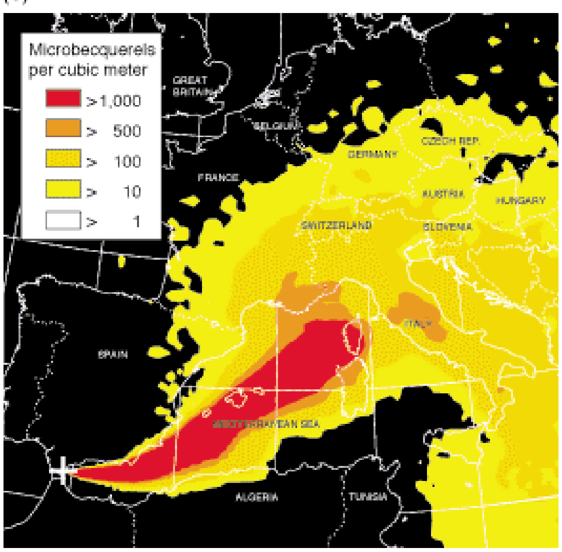


Figure 5. Following a cesium-137 release in southern Spain, ARAC received (a) measurements of elevated radiation levels from disparate European sources, which it superimposed on a terrain map of central and southern Europe. (b) Results from ARAC's third set of simulations for this release show the average air concentrations over a 7-day period. These results led to a good estimate of the original cesium release.

A Tire Fire near Livermore

A large fire in a tire disposal pit challenged ARAC with yet another type of dispersion problem. The fire began late one Friday afternoon in August 1998, on the south side of Tracy, California, just 15 miles east of Lawrence Livermore. The Laboratory's fire chief, whose department provided mutual aid at the scene, called for ARAC assistance late that evening, as the fire continued unabated and plumes of dark smoke grew into large, threatening clouds. The Laboratory's Emergency Duty Officer paged ARAC's on-call meteorologist with the request to forecast the dispersion of smoke over the weekend in the

Central Valley. Shortly thereafter, two ARAC meteorologists arrived at the ARAC Center, ready to start work on the problem.

The tire pit covered about 20 acres and was estimated to be about 100 feet deep. The burning tires, each containing the equivalent of about 1 to 2 gallons of oil, caused a massive black cloud to rise about 5,000 to 7,000 feet above ground level. With only this information, ARAC meteorologists assumed that the fire covered an area of about 2.5 acres and that the smoke consisted of fresh combustion particulate products with a median diameter of one micrometer. Their simulation agreed well with an aerial photograph taken a few hours after the fire started (Figure 6). Their models were used to derive the air concentrations of the particulate at ground level over the next three days.

Later, ARAC went on to evaluate the smoke dispersion on a larger scale, from Sacramento to Fresno. State agencies used the larger assessment to alleviate the public's concerns about health effects from inhaling the smoke or drinking surface water downwind of the fire where the contents of the plume were estimated to have been deposited.

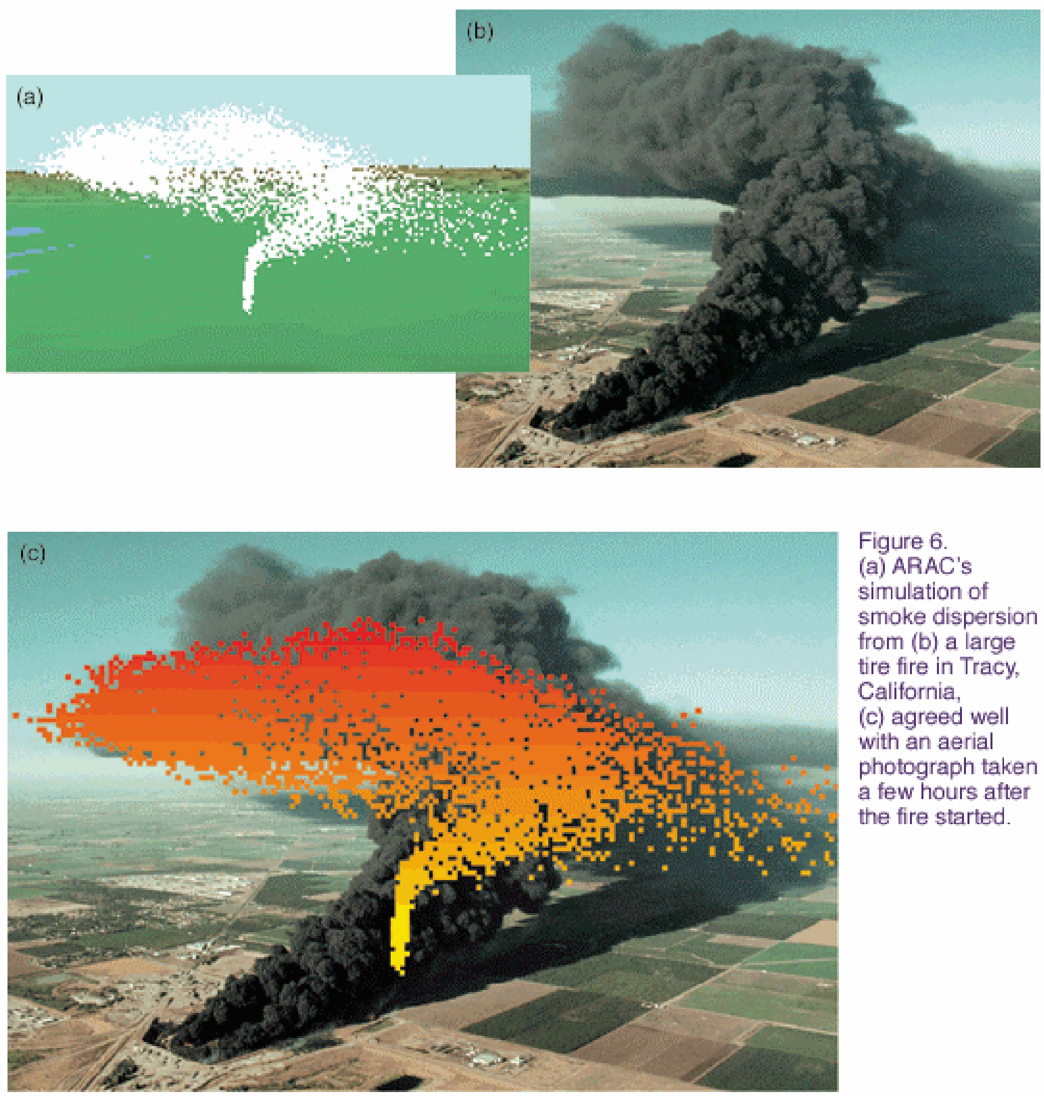


Figure 6.
(a) ARAC's simulation of smoke dispersion from (b) a large tire fire in Tracy, California,
(c) agreed well with an aerial photograph taken a few hours after the fire started.

Moving Ahead of Emerging Risks

As ARAC embarks on its third decade of support to the nation, its cadre of operational atmospheric scientists is taking advantage of the ever-finer model resolution and ever-greater speed made possible by increasingly powerful computers. Their objective is to continually shorten response time and to increase the breadth of their capabilities and the accuracy of their predictions. Although ARAC's emergency readiness role is formally defined by its sponsors, improved capabilities are required to meet emerging risks. For the sake of national security, ARAC must stay ahead of those risks.

-Gloria Wilt, Published in Science and Technology Review, June 1999 at http://www.llnl.gov/str/Baskett.html

Key Words: ADAPT (Atmospheric Data Assimilation and Parameterization Tool), Atmospheric Release Advisory Capability (ARAC), ARAC Emergency Response Modeling System, atmospheric dispersion modeling, Coupled Ocean-Atmosphere Mesoscale Prediction System, emergency incident response, GRIDGEN (Grid Generator), LODI (Lagrangian Operational Dispersion Integrator).

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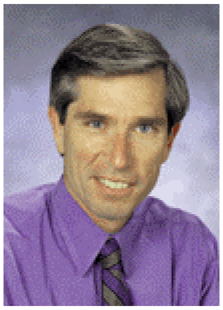
ABOUT THE SCIENTIST



Ronald L. Baskett received his B.S. and M.S. in atmospheric science from the University of California at Davis. Throughout his career, he has focused on the use of measurements and models to solve problems of hazardous atmospheric releases, especially in complex terrain and coastal areas.

Baskett began his career with environmental consulting firms as a manager of meteorological and modeling projects to determine how proposed industrial facilities will affect air quality. In 1983, he joined Livermore's Atmospheric Release Advisory Capability (ARAC) program. He helped develop the software for the ARAC modeling system, performed numerous modeling studies, and gained extensive emergency response experience. He has been involved in about 40 emergencies and alerts worldwide, played a key role in several major field exercises, and supported hundreds of drills and assessments of individual facilities. He currently leads ARAC's operations team.